ILC Research and Development Plan for the Technical Design Phase

Release 2

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ILC Global Design Effort

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1 Purpose of this Document

This document describes the present and planned global Technical Design Phase Research and Development effort in support of the ILC Global Design Effort (GDE).

The ILC Research and Development Plan for the Technical Design Phase document complements the ILC Project Management Plan for the Technical Design Phase released in October 2007 (http://ilcdoc.linearcollider.org/record/11980).

The plan presented here will be periodically reviewed every 6 months, followed by an update and new release of the document.

The document is structured into two parts:

- A relatively short report which summarises the primary goals and schedule for the Technical Design Phases 1 and 2
- A set of appendices which contain detailed information on world-wide resources and the complete project work-package structure

The front report matter is divided into 6 sections:

Section 1 Purpose of this Document: this introduction.

Section 2 Overview of the Technical Design Phase: defines the project structure and the top-level management goals and milestones.

Section 3 Overview of Critical R&D: describes the high-priority risk-mitigating R&D programmes.

Section 4 Machine Design and Cost-Reduction Activities: describes the accelerator design activities which are primarily focused on cost-reduction.

Section 5 Cost and Schedule Planning: describes the TD Phase plans for producing an updated and more robust (defendable) construction cost and schedule estimate for the ILC. This section also includes the TD Phase plans to develop the ILC Project Implementation Plan.

Section 6 Global Coordination: describes how the GDE Project Management intends to coordinate the global activities given the lack of centralised funding.

The appendices are structured as follows:

Appendix A: Summarises the estimated global resources available for the Technical Design Phase.

Appendix B: A description of the project work packages.

Appendix C: An overview of ILC-relevant activities (and resources) at other projects which have a strong synergy with ILC (for example the European XFEL and Project-X).

Appendix D: contains a list of institutes who are either participating or have expressed interest in participating in Technical Design Phase work.

2 Overview of the Technical Design Phase

The Technical Design (TD) Phase of the ILC Global Design Effort will produce a technical design of the ILC in sufficient detail that project approval from all involved governments can be sought. The TD phase will culminate with the publication of a Technical Design Report (TDR) in mid-2012. The key elements of the TDR will be:

- A complete and updated technical description of the ILC in sufficient detail to justify the associated VALUE estimate.
- Results from critical R&D programmes and test facilities which either demonstrate or support the choice of key parameters in the machine design.
- One or more models for a Project Implementation Plan, including scenarios for globally distributed mass-production of high-technology components as "in-kind" contributions.
- An updated and robust VALUE estimate and construction schedule consistent with the scope of the machine and the proposed Project Implementation Plan.

The report will also indicate the scope and associated risk of the remaining engineering work that must be done before project construction can begin.

The TD Project Management team has primary responsibility for delivering the TDR. The Project Management team leads and coordinates the international effort in the three regions (Asia, Europe and North America) needed to complete the Technical Design Phase (TDP) and deliver the TDR. The Project Management structure is summarised in Table 2.1. The project is divided into three Technical Areas which are sub-divided into Technical Area Groups (TAG). Each Technical Area has an associated Project Manager. The fifteen TAG listed in Table 2.1 are each coordinated by a TAG leader, who reports to the respective Project Manager. Specific responsibilities and roles are defined in the Project Management Plan. Each TAG comprises of a set of technical Work Packages (WP), which are summarised in Appendix B.

Table 2.1: TD Phase Technical Areas

	Technical Area		
	1. Superconducting RF Technology	2. Conventional Facilities & Siting and Global Systems	3. Accelerator Systems
Technical Area Groups	1.1 Cavity	2.1 Civil Engineering and Services	3.1 Electron Source
	1.2 Cavity-Integration	2.2 Conventional Facilities Process Management	3.2 Positron Source
	1.3 Cryomodules	2.3 Controls	3.3 Damping Ring
	1.4 Cryogenics		3.4 Ring To Main Linac
	1.5 High Level RF		3.5 Beam Delivery Systems
	1.6 Main Linac Integration		3.6 Simulations

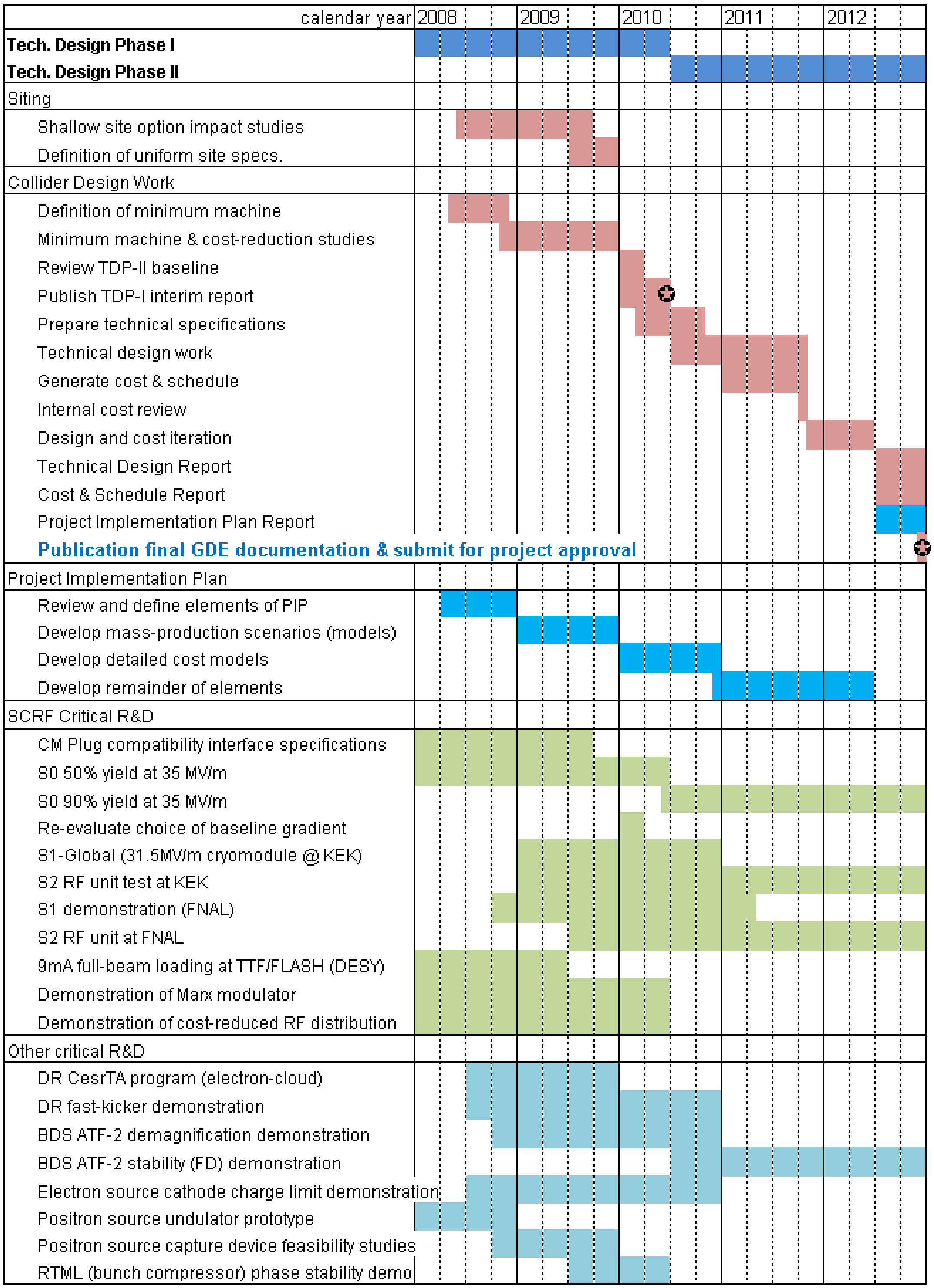
The TD plan is divided into two phases:

- **TD Phase 1** will conclude in mid-2010 with the publication of the TD Phase-1 Interim Report. The emphasis of TD Phase 1 is on high-priority risk-mitigating R&D – most notably the Superconducting RF linac technology – and quantifying the scope for potential cost reduction of the current Reference Design. The end of TD Phase 1 will also see a re-baseline of the conceptual machine design, in preparation for more detailed technical design work in TD Phase 2. The re-baseline will take place after careful consideration and review of the results of the TD Phase 1 studies and the status of the critical R&D.

- **TD Phase 2** (2010-2012) is intended to consolidate the new baseline reference design with more detailed technical design studies leading to an updated VALUE estimate and construction schedule. In parallel remaining critical R&D and technology demonstration milestones will be concluded. A further critical component of TD Phase 2 will be the detailed development of the Project Implementation Plan.

Figure 2.1 shows the current planning for the TD Phase top-level tasks for both Phase 1 and Phase 2. The resources required to complete these tasks within the approximate time-lines depicted are still under review, but it is expected that there are sufficient resources available for the TD Phase 1 activities (*i.e.* consistent with the summary information presented in Appendix B). However, it is expected that successful completion of the TD Phase 2 goals will require an increase in technical and engineering resources world-wide beyond that currently foreseen for TD Phase 1. As of this release, the required level of resources for TD Phase 2 needs to be determined. Specifically, resources for the development of the Project Implementation Plan require review.

Figure 2.1: Tentative schedule for the Technical Design Phase.



3 Overview of Critical R&D

3.1 Superconducting RF Technology (SCRF)

The Superconducting RF (SCRF) Technology Area is responsible for developing and establishing the superconducting RF technology and its system engineering, including Cavity, Cavity integration, Cryomodule, Cryogenics, High-level RF (HLRF), and Main linac integration.

3.1.1 Primary SCRF goals

Specific R&D goals for the SCRF include:

- Cavity: High-gradient R & D with single-cell and 9-cell cavities for the material, mechanical forming, surface-preparation process, and vertical testing, with a goal to achieve a field gradient of 35 MV/m at $Q_0 = 10^{10}$ with the yield >90% (>80% after the first test, achieving >90% after re-processing the remaining 20%). Designated as S0 program (see section 3.1.3);
- Cavity-integration: Plug-compatible cavity-package design and integration including tuner, input-coupler, He-vessel and magnetic shield, and the cavity-string test with average gradient of 31.5 MV/m in one cryomodule. Designated as S1 and S1-global program.
- Cryomodule: Plug-compatible thermally-optimised cryomodule design and integration for cost-effective fabrication.
- Cryogenics: System engineering to establish cost-effective design for both construction and operation. The coordination required to satisfy pressure vessel codes in each region will be investigated.
- HLRF: development of a cost-effective modulator and power distribution system capable of supporting a spread of cavity field gradients within an RF unit (average gradient operation).
- MLI: Optimisation of layout and parameters of the RF unit, including cavity, diagnostic, and quadrupole alignment tolerances. Beam dynamics aspects including wakefield and HOM calculations.
- SCRF-system integration: System integration and test of a baseline RF unit (single MB klystron and modulator driving 26 cavities in three cryomodules in a 9-8-9 configuration with a suitable RF distribution system; quadrupole package at the centre of the 8-cavity cryomodule). Demonstration of an average accelerating gradient of 31.5 MV/m at $Q_0 = 10^{10}$ with full beam-loading and handling. Designated as S2 program.

3.1.2 SCRF Technical design and R&D Milestones

The milestones for the TD Phase 1 and 2 SCRF goals outlined in section 3.1.1 (notably the S0, S1 and S2 programs) are given in Table 3.1.

Table 3.1: Milestones for the SCRF R&D Program.

High-gradient cavity performance at 35 MV/m according to the specified chemical process with a yield of 50% in TDP1, and with a production yield of 90% in TDP2	2010 2012
Nominal Cryomodule design to be optimized: - plug-compatible design including tune-ability and maintainability - thermal balance and cryogenics operation - beam dynamics (addressing issues such as orientation and alignment)	2009
Cavity-string performance in one cryomodule with the average gradient 31.5 MV based on a global effort (S1 and S1-global)	2010
An ILC accelerator unit, consisting of three cryomodules powered by one RF unit, with achieving the average gradient 31.5 MV/m (S2)	2012

3.1.3 SCRF Cavity Gradient R&D

R & D focused on increasing the achievable gradient in superconducting cavities has a large potential impact on the cost of the ILC. The gradient choice made for the Reference Design is 35 MV/m in vertical dewar test even though present day average gradient performance of baseline ILC 9-cell cavities is about 15% lower with a yield of 50%. R & D efforts to improve the yield are focused more on the chemical treatment applied to the inner surface of the cavity just prior to the final high-purity water rinse. Therefore the TD Phase gradient studies make use of a small number of cavities which are chemically processed, tested and re-treated in a tight cycle. This reduces the cost of the R & D effort. Based on recent experience and knowledge obtained, it is very useful to optically map the cavity inner surface as a part of the routine process before and after the chemical process (before the first vertical cold test). It is hoped that this will improve the R&D efficiency and provide a cost-effective feedback loop in the cavity development. The improvement of the diagnostics for hot-spot temperature measurement (temperature mapping system) will also contribute to the localization of the source of a problem in combination with further investigations using the optical inspection system. The improvement of the inspection system (with optical and other approaches) and test facilities are expected to be part of the R&D program in the early TD phase.

The number of ‘process and test’ measurements, each made under prescribed conditions, provides a measure of progress. Table 3.2 shows the anticipated numbers of cavities for testing and the number of ‘process and test’ cycles in each of the three regions. Over eight–hundred cavities will be fabricated in Europe as part of the European XFEL project

This relatively large number of cavities will be processed and tested only once as part of the XFEL production plan[1].

TD Phase goals for gradient R & D are:

1) Routinely achieve 35 MV/m in 9-cell cavities in the low-power vertical dewar tests. Preparation process and vertical test yield for 35 MV/m at $Q_0 = 10^{10}$ should be greater than 50% for a sufficiently large number (greater than 100) of chemical process and test cycles by CY 2010 (TDP1), and 90 % for the cavity production (including 20% re-processing fraction) by CY 2012 (TDP2). Pre-/post-inspection of cavity surface should contribute to improvement in the yield of the chemical process, primarily during the TD Phase 1 R&D.

2) Perform a series of inter-laboratory cavity exchanges in order to maximize the R&D efficiency and, when necessary, cross-check and calibrate infrastructure performance.

3) Review the choice of baseline gradient at the end of TD Phase 1 and again at the end of TD Phase 2.

Table 3.2: Projected number of superconducting RF cavities available in each region and the number of planned tests for the TD Phase (TDP-1 is 2004 to mid-2010), and up to 2012

Americas	US FY06 (actual)	US FY07 (actual)	US FY08	US FY09	US FY10	TDP-1 Totals*	US FY11	US FY12
Cavity orders	22	12		10	10	**52**	10	10
Total 'process and test' cycles		40	5	45	30	**113**	30	30
Asia	**JFY06 (actual)**	**JFY07 (actual)**	**JFY08**	**JFY09**	**JFY10**		**JFY11**	**JFY12**
Cavity orders	8	7	8	25	15	**44**	39	39
Total 'process and test' cycles		21	40	75	45	**147**	117	117
Europe	**CY06 (actual)**	**CY07 (actual)**	**CY08**	**CY09**	**CY10**		**CY11**	**CY12**
Cavity orders	60**	8		834†		**8**		
Total 'process and test' cycles		14	18	26	30	**73**	380	406
Global totals								
Global totals - cavity fabrication	**90**	**27**	**8**	**869**	**25**	**103**	**49**	**49**
Global totals - cavity tests		**75**	**65**	**135**	**175**	**333**	**501**	**501**

* to June 2010

** Thirty European cavities were ordered in 2004.

† 808 cavities for the European XFEL + 26 ILC cavities

[1] The XFEL gradient requirements are lower than the goals for the ILC, but it is hoped that the same high-gradient surface preparation procedures will still be adopted. A final decision is to be made in the third-quarter of 2008. At least 26 cavities from the mass production run will be treated to ILC specifications, irrespective of the choice of the final surface processing for XFEL mass-production.

3.1.4 SCRF Cavity-Integration and Cryomodule R&D

R&D focused on the Cryomodule facilitates the development of a detailed ILC project Implementation plan, including an achievable project schedule and plan for competitive industrialization in all regions. We assume that the ILC project will require a flexible design based on modular sub-components. The TD Phase strategy is to provide the framework for technical and industrial development by specifying the engineering interfaces between the five Cryomodule sub-components, and if possible within them. Through this process, institutional designers and developers can provide "plug-compatible" components for a generic ILC Cryomodule. It is important to note that, for purposes of updating the VALUE estimate, a particular globally agreed-upon design, with a specific set of component choices will be used.

A Cryomodule is composed of five sub-components:

- Cavity unit (9-cell cavity; tuner system; HOM coupler; He-vessel)
- Input-coupler

Note: the coupler needs to be assembled together in the cavity-package prior to the shipment

- Quadrupoles and steering dipoles
- Beam instrumentation (BPM)
- Cold mass (piping and supports) and vacuum vessel

The interface between these sub-components should be well-defined to facilitate interchangeable and plug-compatible component designs. This will allow parallel development of high-technology components across all regions, in support of globally distributed cost-effective mass-production.

The cavity-string, and cryomodule design and R&D are summarized as follows:

1. Establish a baseline Cryomodule design with plug-compatible component interfaces
2. Integration of 8 high-performance cavities into a single cryomodule (not necessarily baseline design) with a view to demonstrating an average of 31.5 MV/m accelerating gradient (S1)

The latter goal will be realized in two stages as described below.

Cavity-string test in one cryomodule (S1 and S1-global)

A set of eight dressed cavities qualified through the high-gradient effort described in 5.1.3 will be installed into a cryomodule and tested to demonstrate the ILC operational gradient of 31.5 MV/m on average (S1). Fermilab will work towards this goal using eight cavities from its own planned production stream. To-date, DESY has achieved an average gradient of nearly 30 MV/m. Plans to construct an ILC-spec. cryomodule at DESY during the XFEL production are under discussion.

An international cooperation program, S1-Global, is redundantly planned to realize the cavity-string performance test as a global effort using the test facility at KEK (STF). Two cavities each will be provided by the American and European effort, with the remaining four cavities being provided by the Asian effort. The program will also address many of the plug-compatibility issues for the cavity and cryomodule.

Cryomodule-string test of an RF unit (S2)

In the second stage, an extended system containing three cryomodules and powered by a single klystron and RF power distribution system will be demonstrated (a single ILC RF Unit). The test will include beam acceleration and beam handling. This is scheduled for the end of TD Phase 2 (2012). The effort to realize S2 in each region is highly encouraged as an important milestone for anticipated regional centres for the ILC construction period.

3.1.5 SCRF High-Level RF R&D

The main focus of the TD Phase High-Level RF R&D program is to develop and test a reference design for the Main Linac RF Unit which meets ILC requirements and has a cost estimate significantly lower than that of the RDR design. Specific targets for cost reductions are the modulator and RF power distribution systems.

Modulator

The RDR baseline modulator is the Fermilab “Bouncer Modulator”. A transformer-less design based on Marx-generator circuits is under development. The Marx-based design is pursued because of potential cost savings and reliability improvements over the Bouncer topology. The projected cost savings assume a lower component cost and a significantly less labour-intensive manufacturing process. A prototype Marx modulator is being developed at SLAC in order to show proof-of-principle and to establish a design that would allow a credible cost estimate. Current projections would make it possible to develop a cost estimate by mid-2010 and hence allow the adoption of the technology as part of the re-baseline to be used in TD Phase 2.

Power Distribution System

The RDR baseline is a linear distribution system with individual tap-offs, circulators, and 3-stub tuners for each cavity. An alternative design using a semi-branched system (two cavities per tap-off) with variable tap-offs is under development and may make it possible to eliminate costly circulators. A critical aspect of the power distribution system activities is to develop low-cost implementations of key RF components such as the variable tap-offs, phase shifters, and loads. An additional focus for the power distribution system is to provide sufficient flexibility and adjustability to compensate for variations in cavity gradient, allowing the total gradient for each cryomodule triplet RF unit to be optimised.

TD Phase-1 Milestone by calendar year middle 2010

- Demonstrate operation of Marx modulator feeding a multi-beam klystron
- Demonstrate performance of key distribution system components

TDP Phase-2 Milestones by calendar year middle 2012

- Perform a full-scale demonstration of an integrated RF system (modulator, MB klystron, power distribution, cryomodules, LLRF, controls). The goal is to perform this test at NML, Fermilab and at STF, KEK. Beam operation is required to demonstrate regulation and control.

3.1.6 Main Linac Integration

Main Linac Integration design work and development in the TD phase includes:

- Integrated beam dynamics simulation (including tuning and feedback modelling) and wakefield calculations to establish tolerances for linac component initial alignment and specifications of beam-based alignment procedures
- Design and development of the linac quadrupole and dipole magnets and key linac beam instrumentation

The primary R&D efforts are required for the quadrupole magnet package design and prototype development in the TD Phase.

3.2 Beam Test Facilities

Beam Test Facilities are required for critical technical demonstrations, including accelerating gradient, precision beam instrumentation and beam dynamics. In each case, the test facility is used to mitigate critical technical risks as assessed during the development of the RDR. The tests can be grouped into 3 categories:

1. Demonstrations of the generation and handling of low-emittance beams using precision optics and stabilisation tools
2. Demonstrations of high-gradient, high-power superconducting accelerator assembly and operation, and
3. Studies of instabilities, such as electron cloud, and mitigation techniques

Because of the importance of developing assembly techniques and perfecting associated infrastructure, high-gradient and string assembly studies have been developed redundantly in more than one region.

Test facilities also serve to train scientific and engineering staff and regional industry. In each case, design and construction of the test facility has been done by a collaboration of several institutes. Table 3.3 summarizes the facilities which have been built or are under construction in each region along with the planned (or actual) operation start date. Table 3.4 shows the TD Phase deliverables from each test facility and estimated schedule.

Table 3.3: Beam Test Facilities (existing or under construction).

Test Facility	Acronym	Purpose	Host Lab	Operation start	Organized through:
Accelerator Test	ATF	Damping Ring	KEK	1997	ATF

Test Facility	Acronym	Purpose	Host Lab	Operation start	Organized through:
Facility					Collaboration
Cornell Test Accelerator	CESR-TA	Damping Ring	Cornell	2008	Cornell
Superconducting RF Test Facility	STF	Main linac	KEK	2008	KEK
TESLA Test Facility/ Free Electron Laser Hamburg	TTF / FLASH	Main linac	DESY	1997	TESLA Collaboration, DESY
ILC Test Accelerator	ILCTA-NML	Main Linac	FNAL	2009	Fermilab
Beam Delivery Test Facility	ATF-2	Beam Delivery	KEK	2008	ATF Collaboration
End Station A (program terminated 2008)	ILC-SLACESA	Machine – Detector Interface	SLAC	2006	SLAC

Table 3.4: TD Phase Beam Test Facilities Deliverables and Schedule.

Test Facility	Deliverable	Date
Optics and stabilisation demonstrations:		
ATF	Generation of 1 pm-rad low emittance beam	2009
ATF-2	Demonstration of compact Final Focus optics (design demagnification, resulting in a nominal 35 nm beam size at focal point).	2010
	Demonstration of prototype SC and PM final doublet magnets	2012
	Stabilisation of 35 nm beam over various time scales.	2012
Linac high-gradient operation and system demonstrations:		
TTF/FLASH	Full 9 mA, 1 GeV, high-repetition rate operation	2009
STF & ILCTA-NML	Cavity-string test within one cryomodule (S1 and S1-global)	2010
	Cryomodule-string test with one RF Unit with beam (S2)	2012
Electron cloud mitigation studies:		
CESR-TA	Re-configuration (re-build) of CESR as low-emittance e-cloud test facility. First measurements of e-cloud build-up using instrumented sections in dipoles and drifts sections (large emittance).	2008
	Achieve lower emittance beams. Measurements of e-cloud build up in wiggler chambers.	2009
	Characterisation of e-cloud build-up and instability thresholds as a function of low vertical emittance (≤20 pm)	2010

3.3 Other critical (risk-mitigating) R&D

The following briefly highlights the identified highest-priority risk-mitigating R&D items for the Accelerator Systems Technical Area Groups, which are expected to be completed within the TD Phases.

3.3.1 Electron source

- Investigation of cathode charge-limit under ILC requirements
- Development of laser system for ILC specs. (required for charge limit tests)
- Development of DC gun and cathodes for ILC specs (required for charge limit tests)

3.3.2 Positron source (baseline undulator-based)

Critical R&D for the TD Phase includes:

- high-velocity rotating titanium target, specifically survivability and eddy current studies
- design of a feasible optical matching device to maximise the yield, this could be a high-field pulsed flux concentrator or a lithium lens system

In addition to the fundamental engineering goals, key deliverables are:

- Full prototype section and evaluation of the superconducting helical undulator (2009)
- Feasibility studies and design of a high-field flux concentrator (2009)
- Feasibility study and design of a lithium lens (2010)
- Engineering design of rotating target system with appropriate lifetime (2010)

3.3.3 Damping Ring

- Demonstration of electron cloud mitigation effects (CesrTA programme, 2010)
- Demonstration of ultra-low emittance (KEK ATF, 2009)
- Development of 5 ns rise-time injection and extraction kickers (DAΦNE experiments, 2010)

3.3.4 Ring-to-Main-Linac (RTML)

- Demonstration of required bunch compressor phase stability with full beam-loading (2010)

3.3.5 Beam Delivery System

The main R&D focus for the BDS is the ATF-2 programme at KEK which will allow demonstrations of many of the key BDS components and design concepts, the Machine-

Detector activity for optimization of the Interaction Region, and design for those BDS subsystems which are critical for system performance or which may expand the physics capabilities of the collider. Examples of R&D are:

- Development of instrumentation (e.g. laser-wires), algorithmic control software, beam-based feedback systems and emittance-preservation techniques to achieve the small beam-size goals (2010)
- Developing of IR Interface Document defining MDI specifications and responsibilities (2010) and design or optimised IR (2012)
- Development of the prototype of the Interaction Region SC Final Doublet (2012)
- Development of Interferometer system for FD stability monitoring (2012)
- Design of the beam dump system (2012)
- Tests of SC and PM Final doublet at second stage of ATF2 (2012)
- Design studies for the photon collider option (2012)
- Collimation and dump window damage tests at ATF2 (2010)
- Development and demonstration of the SCRF crab-cavity system (2010)

4 Machine Design and Cost-Reduction Activities

For TD Phase 1, the primary focus and effort will be strategically directed towards the successful completion of the critical R&D as discussed in Section 3. In parallel to this, a minimal design activity will focus on a detailed review of the cost-drivers of the RDR collider design, with a view to a re-baseline at the end of TD Phase-1. We expect to see an increase in global engineering and technical resources in TD Phase 2 to enable a more detailed conceptual engineering design of the new baseline configuration, resulting in a robust and defendable update of the VALUE estimate by the end of TD Phase 2 and subsequent submission of the TDR.

With a strong emphasis on cost-reduction, the above goals will be achieved as follows:

- Consolidation, review and re-structuring of the RDR information, to allow a solid-bases for further parametric cost studies (end 2008)
- Definition of the basic parameters and layout of a “minimum machine configuration”, as a basis for understand cost-increments and cost-performance trade-offs (beginning 2009)
- Cost-reduction and performance studies (parametric studies) of the minimum machine, leading to possible options for the re-baseline. Evaluation of estimated cost and performance risk impact (end 2009).
- As part of the above, studies of a cost-optimised “shallow site” with a view to defining an optimum ‘reference site’ for further design studies (end 2009).

- Evaluation of cost-reduction studies and status of critical R&D, leading to an agreed re-baseline of the reference machine (end of TD Phase 1, 2010)
- Produce technical component specifications for technical systems; technical design of systems leading to cost estimates; value-engineering iteration (TD Phase 2)
- Generation and publication of TDR with updated technical design and VALUE estimate (end of TD Phase 2, 2012)

The main focus of these activities is in the Conventional Facilities and Siting – where significant potential for cost reduction is expected – and in Accelerator Systems where more cost-driven design options will be considered, in particular with reference to the minimum machine.

4.1 Conventional Facilities and Siting and Global Systems

Conventional Facilities and Siting (CFS) is responsible for the civil engineering of the underground and surface construction, site electrical and cooling systems. Global Systems includes the accelerator-complex Computing and Controls System, and pre-Operations and Commissioning.

The RDR VALUE estimate lists the CFS component as a substantial contributor to the overall project cost. This is to be expected given the extent of underground construction and underground infrastructure foreseen in the Reference Design. During the TD Phase, design for CFS components will be subject to the process of Value Engineering, whereby an attempt is made to assure the highest "value" by delivering all required functions at the lowest overall cost. The TD Phase CFS activities are therefore focused on this activity and are broadly subdivided into three stages:

1. A preparatory stage, during which the design criteria used to develop the Reference Design are revisited and analyzed. Development of design criteria depends critically on input from the Accelerator Systems Technical Groups.
2. A Value Engineering review stage, where the functional requirements are compared one at a time with their respective cost and a small set of prospective improvements are proposed.
3. An evaluation and design update stage during which the design is improved through adoption and analysis of the suggestions.

Work on CFS design is tightly coupled to the Accelerator Systems design development.

Based on expected Accelerator Systems and CFS design and engineering resources for the TD Phase, stages (1) and (2) above are expected to last about two and a half years and the schedule has been developed accordingly (see Table 4.1). Stage 2 Main Linac activities will be completed first (TD Phase 1) because the requirements are more mature and related savings may be significant.

Global Systems R & D activities include work on modelling the controls system, high-availability studies and linac low-level RF controls studies. For this version of the plan, we include only the latter. The Low-Level RF system (LLRF) regulates the phase and amplitude of the High-Level RF (HLRF) power fed to each group of three cryomodules in order to stabilize at the set-point value. It must compensate for disturbances that occur both bunch-train to bunch-train and within each bunch train, including Lorentz force detuning, drift, transient beam-loading. A feed-forward system provides a programming waveform for the LLRF regulator for the upcoming bunch-train based on measured bunch currents in the damping ring.

In order to stabilize the cavity fields, the available maximum power from the HLRF must exceed the nominal operating power level in order to provide operating headroom for the LLRF regulator and to avoid running in the saturation region of the Klystron. Additional RF voltage and power is also needed to handle a distribution in the cavity gradient limits of the cavities. Additionally, the RDR assumes that all 26 cavities fed from each klystron have the same gradient limit, but additional RF power is needed to maximize the gradient vector sum when there is a spread of peak gradient limits.

While it is universally agreed that higher power overhead can improve reliability and technical performance, there is a high cost penalty for RF power, so a minimal cost machine requires optimization of the RF power overhead versus performance. Beam studies are required with fully loaded cavities in order to better assess this optimum; these tests are initially foreseen at TTF / FLASH at DESY.

4.1.1 Primary CFS TD Phase goals

Specific goals for the CFS include:

- Develop and analyze functional requirements as specified by the Accelerator Systems
- Validate the design based on functional requirements
- Execute the ‘Value Engineering’ review process, with special focus on the most costly aspects of the design
    - Underground construction
    - Process water cooling
    - Air handling
    - Surface construction
- Evaluate results of the review process and recommend decisions
- Complete TD Phase effort with an updated and improved baseline

4.1.2 CFS Milestones

CFS Milestones mark progress toward bringing the designs to maturity and to do cost – benefit analysis in order produce a cost / risk optimized design and ILC Project Implementation Plan. These milestones include:

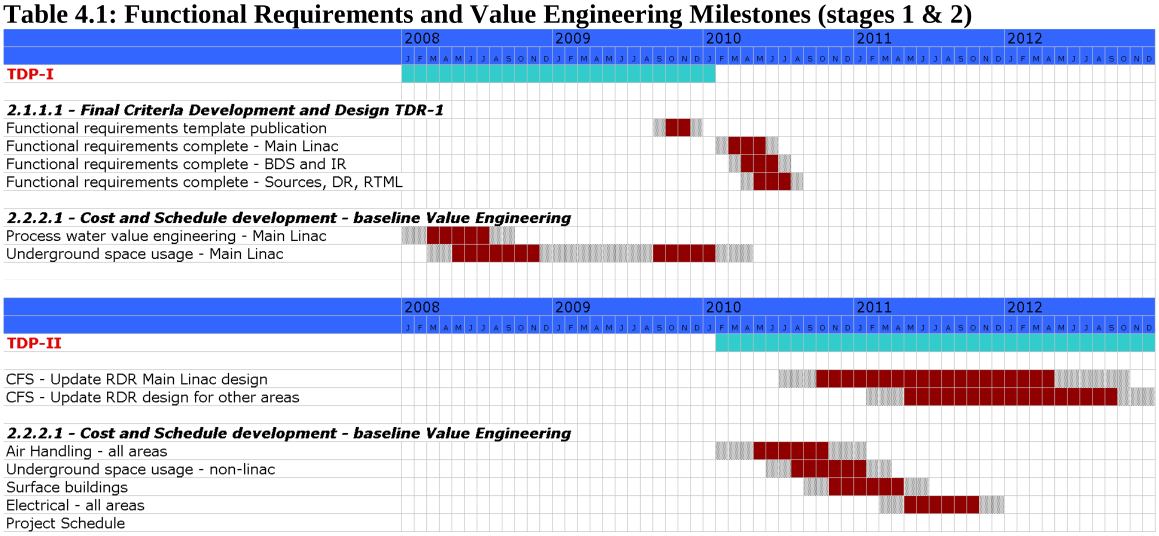
- Defining and delivering technical requirements and criteria to be used in CFS design efforts
- Completing value engineering analysis leading to an Accelerator System and CFS cost / risk optimum design
- Evaluating and deciding which proposed cost-saving proposals will be adopted and included in the TDR

4.1.3 CFS Value Engineering – reducing the cost of Conventional Facilities through analysis of functional requirements

Value Engineering is a proven technique for lowering cost while maintaining required quality. It is particularly applicable during the TD Phase as we carry the pre-conceptual design effort forward from the Reference Design, where the designs of major subsystems, such as the Main Linac power system process water cooling and the underground enclosure air handling is relatively immature. Table 4.1 shows the milestones for the first two stages of the TD Phase CFS activity: 1) developing the functional requirements and 2) Value Engineering reviews.

The bottom half of the table shows the subsystems selected for scrutiny through this process. The costs of these subsystems make up 37% of the RDR value estimate.

Table 4.1: Functional Requirements and Value Engineering Milestones (stages 1 & 2)



4.1.4 Primary Global Systems TD Phase goals

Specific goals for Global Systems LLRF include:

- Demonstrate high-gradient, fully beam-loaded operation with fully operational LLRF control system (TTF/FLASH full 9mA beam-loading high-gradient high-repetition rate operation).
- Determine and recommend the required HLRF overhead budget based on operational requirements

4.2 Accelerator Systems

The Accelerator Systems Technical Area is responsible for the layout, design, performance evaluation and cost estimate for all the sub-systems of the ILC, excluding the Main Linac. Specifically:

- Electron source
- Positron source
- Damping rings
- Ring to main linac (RTML)
- Beam delivery system (BDS) and machine detector interface (MDI)
- Simulations (supports beam dynamics studies across all systems)

4.2.1 Primary Accelerator Systems TD Phase goals

The TD phase goals for the Accelerator Systems are to:

- Define and clearly document performance-driven specifications for the accelerator components and – more critically – CFS
- Iterate with the relevant engineering groups to understand the cost/performance trade-offs, with CFS as a focus
- Demonstrate that the accelerator design fulfils the required performance goals (in a cost-effective way), by demonstration via critical R & D or by simulation
- Maintain design-related risk register, and develop alternative fall-back (risk-mitigating) solutions

4.2.2 Accelerator Systems Milestones

In accordance with the two-phased road-map for the Technical Design Phase, the goals for Accelerator Systems are prioritised into Phase 1 and Phase 2 as follows:

TD Phase 1 (2010)

- R&D into mitigation of high-risk accelerator physics and design aspects of the collider. Specifically demonstration of suppression techniques for electron cloud effects in small emittance beams for the Damping Ring and demonstration of the BDS optics and the required demagnification of the beam at the interaction point. Both of these critical programmes rely strongly on Test Beam Facilities currently in construction (CesrTA and ATF-2 respectively, see section 3.2).

- Consolidation and review of the Reference Design Report machine design and associated VALUE estimate; make selected cost-reduction (performance versus cost) studies, leading to a re-baseline of the machine layout in 2010 in preparation for subsequent technical design and costing activities in Phase 2.
- Continued critical beam dynamics studies to evaluate design performance. In particular understanding cost/performance trade-offs arising from selected engineering studies as needed.

TD Phase 2 (2012)

- Complete (cost optimised) engineering layout of the updated baseline for the all accelerator sub-systems, with consolidated and detailed component lists with specifications suitable for engineering, and accurate enough to support the VALUE estimate.
- Complete CFS criteria tables, which have been reviewed and interacted (value engineered) at least once for each accelerator system.
- Completion of additional selected critical R&D items (specifically in the BDS and electron and positron sources).

5 Cost and Schedule Planning and the Project Implementation Plan

A critical part of the overall design goals outlined in sections 2 and 0 is to produce a robust and defendable VALUE estimate update for the TDR. Two additional and critical components of this task are the development of a construction schedule, and a Project Implementation Plan (PIP). The PIP represents an additional new element compared to the RDR. It will contain (amongst other things) at least one model for globally distributed mass-production of plug compatible high-technology components, as part of an 'in-kind' scenario for the construction of the machine. The PIP has a significant impact on the VALUE estimate and construction schedule. It is therefore important that the published technical design, VALUE estimate, construction schedule and the PIP all be self-consistent.

An initial activity early in TD Phase 1 is to consolidate the RDR VALUE estimate data and design documentation into a new and flexible structure, providing a solid basis for future design and engineering activities. The new data management system must facilitate requirements traceability and support change control, such that careful tracking of the machine design, VALUE estimate and risk register can be performed over the remainder of the TD Phase. The migration of the existing data to the new system is the responsibility of the Cost Management Group (CMG), which includes the senior Project

Management. An initial deliverable of the group is to specify the requirements for the new data system. A critical component of the new system will be the support of construction schedule information via a complete Work Breakdown Structure (WBS). The WBS and associated construction schedule must be consistent with – and based on – one or more models for the global project realisation which will form part of the PIP.

The CMG will maintain top-level ownership of the VALUE estimate data. The group will also be responsible for reviewing internally the cost information and initiating cost-driven design studies where appropriate.

In accordance with the goals set out in Section 0, the consolidated RDR information will be primarily used in TD Phase 1 to support parametric performance versus cost studies, leading to the re-baseline of the machine in 2010. TD Phase 2 will see significant bottoms-up re-evaluation of the VALUE estimate, which will be supported by the cost and schedule tools and methodology established by the CMG during the early parts of TD Phase 1.

The PIP will be developed in several stages during the TD Phases:

- Review existing examples of PIPs and develop and define the elements of the ILC PIP (2009)
- Begin to develop the models for globally distributed mass-production of the SCRF (and other where suitable) components as part of an 'in-kind' project implementation scenario (2010)
- Develop cost models for the SCRF based on the above, which will provide the framework for the SCRF technical groups when estimating their costs during TD Phase 2 (2012)
- Develop the other identified elements of the PIP (2012)

The PIP will be published as part of the primary deliverables of the TD Phase in 2012.

6 Global Coordination

As described in Section 2, the TD Phase R & D is coordinated by the TD Phase Project Management Organization. The effort is subdivided into fifteen functional Technical Area Groups (Table 2.1), grouped into three Technical Areas (Superconducting RF Technology, Conventional Facilities & Siting and Global Systems, Accelerator Systems).

Each Technical Area Group has a Group Leader who reports to a Project Manager. The Group Leader drafts Work Packages and proposes institutional participants and Work Package Coordinators. The term 'Work Package' indicates a task, with a description, needed resources and a tentative schedule, and is a convenient tool for organizing the global community and bringing focus to a given task. The Group Leader is responsible for soliciting, collecting and interpreting Expressions of Interest (EoI) statements that indicate the contribution a given individual or institution would like to make toward the goals of a Work Package or Work Packages of that Technical Area. Responses (as of writing) to the EoI are summarized in Appendix A.

6.1 Inter-regional R&D Coordination

The Technical Area Group Leaders are appointed by the Project Managers based on technical knowledge and inter-regional balance. Because the Group Leader has the most comprehensive knowledge of what is required to meet these goals and a broad perspective of the institutional strengths and aspirations that must be applied to do so, the Group Leaders are responsible for developing and drafting work packages, including goals, milestones and schedules. They also propose Work Package Allocations that indicate which institution or institutions should be responsible for carrying out the work and an individual who should be responsible for Work Package Coordination. Draft work packages respect inter-regional balance and existing institutional programs and priorities. The Project Managers are responsible for developing technical agreements between the TD Project and participating institutions; this includes working with the Technical Area Group Leaders during the Work Package allocation, and submission of proposed Work Packages to managers in the designated institution or institutions for their concurrence and approval.

Appendix A: Summary of Estimate Global Resources

A.1: Resource Base for TD-1 Phase R & D

The resource base information for the TD Phase R &D activities is shown in Tables A.1-3, for each of the three Technical Areas (Superconducting RF Technology, Conventional Facilities & Siting and Global Systems and Accelerator Systems). The tables show anticipated person-years of labour effort and, separately, funds expected to be applied during the TD-1 Phase from 2007 to 2010 for each participating country. The resource information is consistent with possible funding scenarios supplied by institutional and funding program managers. The data in these tables are not those that are guaranteed to be provided. They are the resources needed for accomplishing the plans to the TD Phase. They include not only the resources to be provided directly to the ILC but also the resources for the technology developments that are useful for the ILC.

Table A.1: 2007-2010 Anticipated Resources available in each country (including CERN) for the TD-1 Phase activities – Superconducting RF Technology Technical Area.

		FTE-Years						total M&S						
		Cavities	Cryomodule	HLRF	Cryogenics	ML Integ.	**total FTE-Years**	Cavities	Cryomodule	HLRF	Cryogenics	ML Integ.	**total M&S**	
Americas	**Canada**	18					**18**	1050					**1050**	k$
	USA	73	24	68	5	14	**183**	9169	3960	5909	134	362	**19535**	k$
Asia	**China**	12	8	8	4	1	**33**	10000	10000	10000	5000	1000	**36000**	kRMB
	India	24	12				**36**	1560	900				**2460**	k$
	Japan	45	6	11	4	5	**72**	2225	462	452	180	1119	**4438**	M JY
	Korea	13		5			**18**	1500		245			**1745**	M KRW
Europe	**EU (CERN)**				1	4	**5**					129	**129**	kEUR
	France	94					**94**	10058					**10058**	kEUR
	Germany	51	10	7	7	9	**83**	1705	361			23.5	**2089**	kEUR
	Italy	38	8		1	1	**48**	1182	160				**1342**	kEUR
	Poland													kEUR
	Russia	2	20				**22**	20					**20**	k$
	Spain		3				**3**		9				**9**	kEUR
	Sweden													kEUR
	Switzerland													kEUR
	UK													kGBP
		370	**90**	**99**	**21**	**34**	**615**							

Table A.2: 2007-2010 Anticipated Resources available in each country (including CERN) for the TD Phase activities – Conventional Facilities & Siting and Global Systems Technical Area.

		FTE-Years			total M&S			
		CFS	Controls	total FTE-years	CFS	Controls	total M&S	
Americas	Canada							k$
	USA	12	18	**30**	1397	1098	**2495**	k$
Asia	China		8	**8**		1000	**1000**	kRMB
	India							k$
	Japan	3	5	**8**				M JY
	Korea	1	1	**2**	40		**40**	M KRW
Europe	EU (CERN)	2					**0**	kEUR
	France		18	**18**		307	**307**	kEUR
	Germany	3	14	**17**		63	**63**	kEUR
	Italy		4	**4**		80	**80**	kEUR
	Poland		20	**20**		248	**248**	kEUR
	Russia	2		**2**	40		**40**	k$
	Spain							kEUR
	Sweden							kEUR
	Switzerland		3	**3**		90	**90**	kEUR
	UK							kGBP
	(mixed)		11	**11**		95	**95**	kEUR
		23	**102**	**112**				

Table A.3: 2007 - 2010 Anticipated Resources available in each country (including CERN) for the TD Phase activities – Accelerator Systems Technical Area.

		FTE-Years							total M&S							
		Elec. Source	Posi. Source	Damping Rings	RTML	Beam Delivery	Simulations	total FTE-years	Elec. Source	Posi. Source	Damping Rings	RTML	Beam Delivery	Simulations	total M&S	
Americas	Canada			5				**5**			20				**20**	k$
	USA	11	8	28	1	48	16	**113**	617	144	7174	3	3847	190	**11975**	k$
Asia	China			12	4	20	2	**38**		500	5000	100	200	100	**5900**	kRMB
	India															k$
	Japan	2	7	16		23	4	**52**			722		375		**1097**	M JY
	Korea			2	2	4	3	**12**			26	26	201	26	**279**	M KRW
Europe	EU (CERN)			2		1	4	**7**			7		2.3	8.6	**18**	kEUR
	France		11		5	12		**27**		390			6		**396**	kEUR
	Germany		22	3		4	4	**33**		32	7		36	14	**88**	kEUR
	Italy			17				**17**			300				**300**	kEUR
	Poland															kEUR
	Russia															k$
	Spain					2		**2**								kEUR
	Sweden				2	2		**3**								kEUR
	Switzerland															kEUR
	UK		10	11		85		**106**		35	62		1537		**1634**	kGBP
		13	**57**	**97**	**14**	**201**	**33**	**415**								

A.2: Summary of Work Package Participation

Tables A.4-6 shows the global institutional participation in the Technical Area Group Work Packages. Each of the tables shows, in a separate sub-table for each of the Technical Area Groups, the institutions who have indicated *Expressions of Interest* in the activities planned for that Technical Area Group. Because of ongoing program development, in some cases resources related to Expressions of Interest are not consistently reflected in Tables 6.1-3. (Appendix D: lists and defines the institute abbreviations in tables.)

Table A.4: Institutions participating in Superconducting RF Technology Technical Area Work Packages

Cavities		
Americas	Canada USA	Triumf ANL, Cornell, FNAL, FSU, LLNL, Jlab, SLAC
Asia	China India Japan Korea	IHEP、Beijing University BARC, IUAC, RRCAT, TIFR, U. Delhi, VECC KEK KNU, PAL
Europe	France Germany Italy	LAL/Orsay, Saclay DESY INFN
Cryomodules		
Americas	US	ANL, FNAL, Jlab, SLAC
Asia	China India Japan	IHEP BARC, IUAC, RRCAT, TIFR, U. Delhi, VECC KEK
Europe	 France Germany Italy	CERN Saclay DESY INFN
Cryogenics		
Americas	Canada USA	Triumf ANL, BNL, FNAL, Jlab, SLAC
Asia	India Japan	BARC, IUAC, RRCAT KEK
Europe	 Germany	CERN DESY
High Level RF		
Americas	US	FNAL, SLAC
Asia	China	IHEP
	India	BARC, RRCAT
	Japan Korea	KEK KNU
Europe	Germany	DESY
Main Linac Integration		
Americas	US	FNAL, SLAC
Asia	China	IHEP
	Japan	KEK
Europe	Germany Spain	DESY CIEMAT

Table A.5: Institutions participating in Conventional Facilities & Siting and Global Systems Technical Area Work Packages

CF&S		
Americas	USA	FNAL, SLAC
Asia	Japan	KEK
Europe		CERN
	Germany	DESY
	Russia	JINR
Controls		
Americas	USA	ANL, LBNL, FNAL, Jlab, SLAC, UIUC, UPEN
Asia	China	IHEP
	Japan	KEK
Europe	Italy	INFN
	Germany	DESY

Table A.6: Institutions participating in Accelerator Systems Technical Area Work Packages

Electron Source		
Americas	USA	SLAC, FNAL, Jlab
Asia	China	Tsinghua University
	Japan	Hiroshima U, KEK, Nagoya U
Positron Source		
Americas	USA	ANL, BNL, Cornell, FNAL, LLNL, SLAC
Asia	China	IHEP
	Japan	Hiroshima U, KEK
Europe	France	Orsay
	Germany	DESY
	UK	Daresbury, Liverpool U., Durham U., Manchester U., RHUL
	Ukraine	KIPT
Damping Ring		
Americas	Canada	UBC
	USA	ANL, Cornell U., FNAL, LBNL, SLAC, UIUC
Asia	China	IHEP
	Japan	KEK
	Korea	KNU
Europe	Germany	DESY
	Italy	INFN
	UK	Cockcroft Inst.
RTML		
Americas	USA	Cornell U., FNAL
Asia	China	IHEP
	Japan	KEK
	Korea	KNU
Europe	Germany	DESY
	Russia	Efremov, JINR
	UK	? (tbc)
BDS		
Americas	USA	BNL, Colorado U., FNAL, Iowa U., Jlab, LANL, LLNL, LBNL, MSU, Notre Dame U., Oregon U., SLAC, Wisconsin U., Yale U.

Asia	China	IHEP
	India	BARC, RRCAT
	Japan	KEK, Kyoto U., Tohoku U., U. of Tokyo
	Korea	KNU, PAL
Europe		CERN
	France	LAL/Orsay, LAPP, Saclay
	Germany	DESY
	Russia	BINP, JINR, Moscow U.
	Spain	IFIC
	UK	Abertay U., Birmingham U., Cockcroft Inst., Cambridge U., Dundee U., IPPP Durham, Lancaster U., Liverpool U., Manchester U., Oxford U., RHUL, UCL
Simulation		
Americas	USA	Cornell U., FNAL, SLAC
Asia	China	IHEP
	India	BARC, RRCAT
	Japan	KEK
	Korea	KNU
Europe		CERN
	France	LAL/Orsay
	Germany	DESY
	UK	Cockcroft Inst., IPPP Durham, Liverpool U., Manchester U., Oxford U., RHUL

Appendix B: TD Phase Work Packages

As noted in Section 4, each Technical Area Group Leader is responsible for soliciting, collecting and interpreting Expressions of Interest (EoI) statements that indicate the contribution a given individual or institution would like to make toward the goals of a Work Package or Work Packages of that Technical Area. The Work Packages shown in this Appendix have been assembled and summarized based on the EoI submitted to each technical area group leader. Some Expressions of Interest describing work broadly based on bilateral Memoranda of Understanding between pairs of institutions have also been integrated into the following Work Package tables so as to be consistent from a technical point of view.

B.1: Superconducting RF Technology (SCRF)

TA-1.1 Cavity

Technical Area Group 1.1 Cavity includes the development and test of high-gradient superconducting RF cavities. Specific responsibilities are centred on understanding and managing the limits of cavity performance.

Critical R&D for the TD Phases includes:

- Achieve 35 MV/m in 9-cell cavity in vertical dewar tests with a sufficient yield
- Perform a series of inter-laboratory cavity test program and in order to make efficient R&D and for cross-check the infrastructure performance
- Deliver a gradient recommendation sufficiently prior to the end of TD Phases

Key deliverables are

- Specification of the cavity fabrication and processing procedure
- Specification of cavity interfaces with plug-compatibility

This Group has a single work package containing 4 sub-packages of: 1) gradient performance, 2) fabrication specification, 3) process specification, and 4) cavity shape/material specification, as listed in Table B.1. The highest priority and most prominent activity are in sub-work package 1, ‘Gradient Performance’.

Table B.1: Cavity Processing Work Packages

ID	Title	Description
1.1.1	Cavity prep. & spec	- Single-cell R&D - focus on final rinse after electropolishing before high pressure water rinse, - 9-cell R&D with repeated processing and testing of cavities, including exchange of cavities between institutes and regions. - Production-like effort, including fabrication, processing and testing of cavities. This includes monitoring XFEL production (Appendix A.5), and the development of new vendors) - Based on R&D, specify material and fabrication. - Process specification - Interface, Shape, Flange Seal, Lorentz detuning, Beam dynamics.
1.1.2	Cost & Industrialisation	Cost estimate and industrialisation value engineering.

TA-1.2 Cavity Integration

Technical Area Group 1.2 Cavity-Integration includes the design and development of the cavity package. The cavity package includes the cavity itself, the surrounding helium vessel, the input power coupler, the magnetic shield, and the tuner mechanism. It includes sub-assembly, which becomes the basic building-block of the cryomodule string.

Critical R&D for the TD Phase includes:

- Development of the cavity slow and fast tuner mechanism.
- Development of the cavity helium vessel and associated magnetic shielding. The material for helium vessel is a major issue for the development of a cost-effective approach to cavity assembly/fabrication. Currently, titanium is the baseline material for the helium vessel and is a known cost driver. Stainless-steel offers a cost-effective alternative providing a good bi-metallic junction with the niobium cavity material can be made.

Key deliverables are:

- Definition of criteria and selection of plug-compatible baseline coupler and tuner specifications.
- Multi-cavity string performance test in the cryomodule. This is one of two critically important subjects for R&D and demonstration in the SCRF area. The multi (8~9) 9-cell cavities should be assembled into a cryomodule in horizontal position and should be tested to achieve a nominal operational gradient of 31.5 MV/m at $Q_0 = 10^{10}$ including associated equipment such as tuners, input-couplers, HOM. The successful result should be achieved in multiple regions, and

three test results should be demonstrated globally. The European program is progressed as part of the XFEL R&D program with less performance requirement.

- Completed cavity value engineering process.

Technical Area Group 1.2 Cavity Production/Integration has five work packages listed in Table B.2. The highest priority and most prominent activity is in work package 1.2.5 Integration & Test.

Table B.2: Cavity Integration Work Packages

ID	Title	Description
1.2.1	Tuner	Development of slow tuner for resonance stabilization and fast tuner for Lorentz detuning compensation
1.2.2	Input Coupler	Development of coupler designs, including evaluation of fixed/variable coupling, port diameter, heat load, etc.
1.2.3	Magnetic Shield & He-Vessel	Determination and test of magnetic shielding method, inside/outside He-vessel. Vessel material, bi-metallic junctions, Pressure Vessel regulation, and alignment method.
1.2.4	Integration/Test	system integration into cryomodule and performance test
1.2.5	Cost & Industrialization	Cost estimate and pre-industrialization value engineering

TA-1.3 Cryomodule

Technical Area Group 1.3, Cryomodule, has seven work packages as listed in Table B.1. The highest priority and most prominent activity is in work package 1.3.1 Standardization with "plug-compatibility".

Critical R&D for the ED phase includes:

- Development of a modular, or plug compatible, design concept to allow flexibility in construction planning. Specifically, plug compatible interface definitions to other system/component should be established to prepare for cryomodule manufacturing in industries in multiple regions.

- Design and optimization of the cryomodule cooling system. The maximum pressure and the pressure drop across the cryomodule as well as cooling procedure for the cryomodule should be optimized. Thermal balance should be investigated with 5K shield simplification, and the best design should be concluded in balance of the capital cost for the cryomodule and cryogenics, including operational cost (electrical power cost) for the cryogenics.

- Development of the process for quadrupole magnet installation into the cryomodule. The location and suspension of the quadrupole assembly should be studied with regard to initial alignment and stability (slow drifts and fast vibration) during operation. This must be balanced against the needs of the dust-free assembly procedures required for the cavity string.

- Development of the cryomodule assembly process. Application of the value engineering process to cryomodule assembly.

- Cryomodule system testing. It is important to establish test facilities with the associated cryogenics and RF power systems in each region, in order to evaluate the cavity string and cryomodule performance. Each region should provide a test facility which will be internationally qualified using an agreed-upon set of standards.
- Development of cryomodule transportation schemes. This enables each region to share the SCRF cryomodule production. Investigate the possibility of vertically suspending the cryomodule since that may enable a smaller diameter vertical shaft size resulting in lower civil engineering costs.
- The value engineering should be made for cost/performance optimisation. Design-for-manufacture and the subsequent industrial experience from the LHC magnets and eventually the European XFEL cryomodule will provide significant input to this process.

Key deliverables are

- Establishment of a comprehensive interface and specification document
- Completion of a documented cryomodule design

Table B.1: Cryomodule Work Packages

ID	title	Description
1.3.1.	Standardization	Establish basic design parameters, plug compatible interface conditions, and high-pressure gas code (regulation) issues.
1.3.2.	Cooling pipe configuration and 5 K shield	- Calculation of pressure drops, definition of the maximum pressure, cooling procedure, new piping on the module transverse cross section. - Calculation of thermal-balance with or w/o 5 K-shield Trade-off with cryogenics operation cost.
1.3.3.	Quadrupole Assembly	Quadrupole location, support, installation procedure, alignment, vibration, current leads.
1.3.4.	Assembly Process & Engineering design with CAD	- Study of Assembly procedure, fixtures, facilities, - Study of inter-connect procedure. - Systematic engineering design using 2D/3D CAD, - R&D for technically critical components such as Ti-SUS junction, vacuum components, etc.
1.3.5	Systematic performance evaluation	Establish performance testing process, procedures and design the test facility and define its role during the mass production stage.
1.3.6.	Transportation	Seek transportable cryomodule (region to region) Investigate transportation down to the tunnel through vertical shaft, with inclination (to save shaft size).
1.3.7.	Cost/Industrialization	Cost estimate based on Baseline Configuration, and Industrialization effort (mass production and reducing the cost)

TA-1.4 Cryogenics

Technical Area Group 1.4, Cryogenics, has eight work packages listed in

Table B.2. The first four work packages are specific to the Main Linac cryogenics, and the next four work packages are for other accelerator systems. The last two work packages are for vacuum systems closely coupled with the cryogenics.

Critical R&D for the TD Phase includes:

- Empirical determination of dynamic heat loads using test facilities
- Cryoplant engineering
- Evaluation and comparison of pressure vessel regulations
- Design of non-main linac cryogenic systems

Table B.2: Cryogenics Work Packages

ID	title	description
1.4.1.	Heat loads	The heat load to the entire cryogenics system is investigated under static and dynamic conditions. Static, dynamic, distribution system loads are considered, including tolerances and uncertainties.
1.4.2.	Cryoplant (surface)	The cryogenics plant engineering is to be carried out in cooperation with industry and in close communication with CF&S technical area engineers to optimize interface with the CFS system. The location and distribution of surface equipments such as large compressors and associated utilities are optimized in balance of reliability /maintainability and cost.
1.4.3.	Cryogenics (in tunnel)	The long-term and stable operation is a critical requirement. Studies of segmentation, load-sharing, and maintenance scenario are to be made to keep the system redundancy in balance of the global cost. The cryogen distribution box capacity, location, and distribution in the tunnel, are designed and optimized in balance of the performance/redundancy and cost. The liquid helium level in the cavity and He vessel is an important design parameter to ensure safe and reliable operational condition. The static and dynamic operational conditions are studied and a level control operation is designed and optimized by using heaters. Trade-off studies that compare cryomodule complexity and cost for cryogenic system loads 4K to 2K heat transfer to pumped vapour, pre-cool liquid supply. Safety plan against oxygen deficiency hazard (ODH) in tunnel and surface building is investigated.
1.4.4.	Venting, pressure limits, piping standard	The high pressure gas design needs to fit to any regional codes and constraints. The peak pressure in the cryogenics system in various modes of pre-cooling, steady state operation, emergency modes such as SRF cavity quenches and vacuum failure modes should be carefully studied including the inspection pressure to be required.

1.4.5	Other cryogenic systems (sources, DR, BDS etc.)	Cryogenics for e+, e- source linac, undulators, DR, BDS, RTML, and associated distribution and special objects, as unique and separate from Main Linac. The cryogenic engineering should be similar to that of the main linac system, with a smaller scale. These systems must be properly integrated into the ML cryogenics system.
1.4.6.	Main Linac Vacuum.	The vacuum systems for thermal insulation in all cryogenics system in ML, e+/- sources, BDS, RTML are designed in close cooperation with cryogenics system design. The vacuum system for beam pipe is designed as separate system, in this work package.
1.4.7.	RTML vacuum.	
1.4.8	Cost	The cost is to be optimized in both of capital and operational cost.

TA-1.5 High-Level RF

Technical Area Group 1.5 High-Level RF (HLRF) includes the pulse microwave power generation and power distribution system. Key components are the modulator charger power supply, the pulse modulator, the klystron and the waveguide-based power distribution system.

Critical R&D for the TD Phase includes:

- Development and demonstration alternate modulator and Klystron designs
- Demonstration of flexible power distribution system
- Development and integration of a high-availability interlock and control system

HLRF has five work packages listed in Table B.3. The primary R&D efforts are on cost effective RF power generation and distribution systems.

Table B.3: High-Level RF Work Packages

ID	title	description
1.5.1.	Modulator	Develop; test alternate Marx Modulator & its industrialized design-for-manufacture version. Advance baseline 'Bouncer' modulator design and 50kV design. Develop selection criteria and select a baseline modulator for the TD Phase.
1.5.2.	Klystron	Baseline development of multi-beam klystrons with industry (DESY, KEK). Evaluate multi-beam klystrons in test facilities (DESY, SLAC). Develop sheet beam klystron prototype followed by 'design for manufacture version at SLAC. Develop 50 kV Mega-multi-beam klystron prototype at KEK in collaboration with industry. Accumulate test data and apply selection criteria for the TD Phase baseline
1.5.3.	RF power distribution	Complete development and optimization of components with industry. Participate in the selection process for XFEL.

		Complete SLAC alternate variable tap-off, circulator-less design and perform prototype testing. Complete testing on cryomodules at NML (FNAL) and KEK. Complete new cost estimate.
1.5.4.	HV charger system	Design, prototype, test alternates to the baseline power system (SLAC). Install system for operational testing at (SLAC). Collaborate and track design progress at XFEL.
1.5.5.	Interlock and Control	Develop a programmable fast/slow interlock card in VME and construct and test a complete RF station system at SLAC. Track and participate in the similar development for the XFEL (Europe).
1.5.6.	Industrialisation/cost	The value engineering and industrial R&D to be reflected to the cost.

TA-1.6 Main Linac Integration

Technical Area Group 1.6 Main Linac Integration includes accelerator design and beam dynamics for the Main Linac. This includes development of linac component fabrication, performance and placement tolerances, linac beam dynamics analysis and beam tuning analysis and overall linac system performance specifications.

Critical R&D for the ED phase includes:

- Integrated beam dynamics simulation including tuning and feedback effects
    - Specification of linac component initial alignment and
    - Specification of beam-based alignment procedures
- Design and development of the linac quadrupole and dipole magnets
- Design and development of key linac beam instrumentation

Main Linac Integration has seven work packages listed in Table B.4. The primary R&D efforts are required for the quadrupole magnet package design and prototype development in the TD Phase.

Table B.4: Main Linac Integration Work Packages

ID	title	description
1.6.1	Quadrupole Package Design & Prototype	Specify complete quadrupole package design; develop prototype and test.
1.6.2	Linac beam dynamics	Optimized lattice and identification of emittance 'drivers': Specify linac alignment requirements. Specify allowable energy errors: Evaluation of effectiveness of the various tuning algorithms. Specify requirements to maintain small beam emittance during operation.
1.6.3	Wakefield & Cavity Topics	Examine relevant cavity design and wakefield issues for Main Linac. Evaluate multipacting in power and HOM couplers.
1.6.4.	Cost	General cost optimization with integration with other groups.

B.2: Conventional Facilities & Siting and Global Systems

TA-2.1 Civil Engineering and Services

All Civil Engineering and Services Work Packages are focused on providing a comprehensive review of all existing criteria and an improvement of the overall design solution, while developing a revised cost estimate and project schedule and the effort needed to define and produce the TD Phase.

Each Work Package must completed (deliver) a table (based on CFS template) for key criteria for the civil works specific to that specific region or sample site, including a revised associated cost estimate and project schedule.

Table B.5: Civil Engineering and Services Work Packages

ID	title
2.1.1.1	Civil Works specific to the Americas Regions sample site
2.1.1.2	Civil Works specific to the Asian Region sample site
2.1.1.3	Civil Works specific to the European Region sample site
2.1.1.4	Electrical Engineering (all three sample sites)
2.1.1.5	Air Treatment Equipment (all three sample sites)
2.1.1.6	Process Cooling Water and Piped Utilities (all three sample sites)
2.1.1.7	Vertical Handling Equipment (all three sample sites)
2.1.1.8	Safety Equipment (all three sample sites)
2.1.1.9	Survey and Alignment (all three sample sites)
2.1.1.10.	TD Phase 1 Cost Estimate
2.1.1.11	TD Phase 1 Construction Schedule

TA-2.2 Conventional Facilities Process Management

Table B.6: Conventional Facilities Process Management Work Packages

ID	title	description
2.2.1.1	Finalize list of Work Packages and Sub-work Packages	Management of CFS work.

2.2.1.2	Develop Work Package Assignments and Co-ordinators	Management of CFS work.
2.2.1.3	Develop Pre-Construction Project Schedule	Produce a time schedule that reflects the overall project efforts needed up to the start of construction.
2.2.1.4	Develop Final Criteria for Main Linac and Related System Integration	Establish and maintain points of contact, regular meetings, review process for main linac system integration activities; manage the effort for the refinement and integration of the criteria needed from all area systems
2.2.1.5	Develop Final Criteria for Sources, Damping Ring and RTML and Related System Integration	Establish and maintain points of contact, regular meetings, review process for Sources, DR, RTML system integration activities; manage the effort for the refinement and integration of the criteria needed from all area systems
2.2.1.6	Develop Final Criteria for BDS and Interaction Region and Related System Integration	Establish and maintain points of contact, regular meetings, review process for BDS, IR system integration activities; manage the effort for the refinement and integration of the criteria needed from all area systems
2.2.2	CFS TD Phase Cost and Schedule Development	Develop strategy and prioritization for additional value engineering reviews and alternative investigation. Implement these reviews and investigation per plan
2.2.2.1	Baseline Value Engineering	Schedule and manage Value Engineering (or equivalent process) for all accelerator areas CFS cost-drivers
2.2.2.2	Overall Time Schedule Development	
2.2.2.3	Alternative Investigation	evaluate fundamental alternatives to the baseline design with regard to cost savings and design improvement.

TA-2.3 Controls

Controls includes the integrated accelerator control system hardware, software, central computing, front-end electronics, network infrastructure, low-level RF systems, timing system, precision RF phase distribution, and machine protection systems.

Critical R&D for the TD Phase includes:

- Developing LLRF control models and algorithms that can meet the stringent phase and amplitude requirements
- Research the application of high-availability techniques in the context of accelerator control systems, and assess the potential cost-benefit for ILC
- Develop and evaluate techniques for distributing precision RF phase references over short and long distances (tens and thousands of meters, respectively)

In addition to the fundamental engineering goals, key deliverables include:

- Prototypes of LLRF control models and algorithms, with analytical and experimental evidence showing that they meet ILC RF performance requirements

- A cost benefit assessment of high-availability techniques for electronic systems and their applicability to the ILC control system
- Proof-of-concept prototypes of short- and long-baseline RF phase distribution systems, with analytical and experimental performance data, and a prototype system for in-situ evaluation at a beam test facility

Table B.7: Controls Work Packages

ID	title	Description
2.3.1	Electronics Platform	Investigate the suitability of the ATCA (“Advanced Telecom Computing Architecture”) electronics platform as a High Availability compliant standardized electronics platform for the ILC accelerator control system.
2.3.2	High availability	Research the application of high availability techniques in the context of accelerator control systems. We examine those techniques where the application to controls is not well understood.
2.3.3	Controls system architecture	This track involves researching and documenting the overall control system architecture. Included here are the site-wide controls network infrastructure, client applications tier, services tier, technical equipment tier, and protocols.
2.3.4	Engineering	Engineering analysis needed for design including the risk analysis, value engineering analysis and cost optimization. This will need to include the impact of baseline configuration changes such as the 1 tunnel solution.
2.3.5	Software Development	Software development in an international environment is a difficult problem. Each institution has its own methodology including build, distribution, and deployment practices. Software will need to be tested/verified in an integrated offline environment.
2.3.6	Configuration	Research configuration management tools, data , workflow, and standards for the comprehensive management of the control system configuration.
2.3.7	Integration	In order to meet the very stringent requirements for overall system reliability, as well as provide for more efficient R&D and long-term maintenance, standards must be applied to the technical equipment for packaging, field bus, communication protocol, cabling, configuration, and remote diagnosis.
2.3.8	Timing and Synchronization	The ILC controls system needs R&D on distribution techniques for the 1300 MHz timing distribution system. The specified phase stability requirement for timing across the 15 km accelerator complex pushes the state-of-the-art in stable RF signal distribution. The intent is to build on recent systems at SNS, DESY/TESLA and KEK and ongoing work at SLAC and ANL.
2.3.9	Project Management	Provide Group management for all controls workpackages.
2.3.10	Safety System	Machine Protection, Personnel Safety Systems conceptual design, including tunnel zones and locations of movable beam-stops to support phased machine commissioning
2.3.11	Automation	Investigate and deliver concepts and systems for automation of operation of subsystems like slow orbit feedbacks, energy monitoring, …

2.3.12	Operator Console Application	Test and evaluate new operator application design and functionality for large facilities
2.4.1	LLRF System Requirements and Integration	Capture functional and non-functional requirements, document and review.
2.4.2	LLRF Hardware - Microwave	Develop the Receiver, Up-converter, LO distribution, calibration reference and cable plant for a RF station
2.4.3	LLRF Hardware - Digital	Develop the Cavity Field Controller, Cavity Simulator and Piezo controller. Includes analog and digital IO.
2.4.4	LLRF Software Controller	controller includes field detection, field control algorithm, cavity simulator, front-end, piezo controller and klystron drive, compensation of Lorentz force detuning and beam current compensation
2.4.5	LLRF Software Applications	Application includes cavity detuning, loaded Q, loop gain, vector sum calibration, adaptive feed forward system identification and so on.
2.4.6	LLRF Software Automation	Define the automation concepts such as statemachine , define events and procedure
2.4.7	Evaluation of LLRF prototype systems at test facilities	Develop test plan of LLRF system components at test facilities where possible. Determine acceptance criteria as related to system requirements.

B.3: Accelerator Systems

In the following sub-sections, the primary scope, TD Phase goals and Work Packages for each Accelerator System Technical Area Group will be summarised.

TA-3.1 Electron Source

The Electron Source includes the laser-driven photo-cathode polarized electron high-voltage gun, the conventional radio-frequency capture and bunching system, the 5 GeV 1.3 GHz superconducting injector linac, spin rotation system and associated transport lines connecting to the damping ring. Responsibilities include all associated accelerator beamline components (magnets, vacuum, instrumentation), but not the superconducting injector linac, with the exception of specifying its general parameters and CFS requirements.

Critical R&D for the ED phase includes:

- Development of the laser system for the polarized laser-injector
- Fundamental R&D into polarized photo-cathode materials (charge limit)
- Development of conventional RF capture structure

In addition to the fundamental engineering goals (section) key deliverables are

- Feasibility study of the laser system, including a full design and possible prototype

- Prototype capture cavity

Table B.8: Electron Source Work Packages

ID	title	description
3.1.1	Laser System	Design and eventual prototyping of pulsed laser system matching ILC requirements.
3.1.2	Polarised DC Gun	Design and eventual prototyping of high-voltage DC gun, including structure, power supply and cathode load-lock system.
3.1.3	Polarised Photo-cathode	Development of high quantum-efficiency photo-cathodes with high-polarisation, and increased life-times.
3.1.4	Capture and bunching section	Design and eventual prototyping of the RF systems for sub-harmonic buncher and L-band buncher.
3.1.5	Dumps and collimators	Specification, design and costing of beam collimator and dumps systems.
3.1.6	Polarisation Issues	Specification and design of polarimeters; design of spin-rotation system (lattice); spin-tracking simulations.
3.1.7	Accelerator Physics	Overall optics lattice design, tracking and yield simulations. Basic component specifications *etc.*
3.1.8	CFS interface	Responsible for collection and consolidating the critical key CFS requirements (space, water cooling, power etc.). This work package acts as the primary contact to the CFS Technical Areas.
3.1.9	Design	Overall coordination and management of design activities; system integration, baseline configuration etc.
3.1.10	Magnets	Conceptual/engineering design of conventional magnets and supports.
3.1.11	Power supplies	Specifications, layout and cable layout of magnet power supplies
3.1.12	High-Level RF	Specifications, design and layout of capture section RF power source klystrons, modulators, waveguide distribution system.
3.1.13	LLRF and Controls	Specification of LLRF and controls requirements
3.1.14	Beam Instrumentation	Specification, design and eventual prototyping of required beam instrumentation, including timing requirements and controls interface specifications.
3.1.15	Beamline Vacuum	Specification and design of the vacuum system (not including SRF cold vacuum section).

TA-3.2 Positron Source

The Positron Source includes: the ~1 km warm insert located at the 150 GeV point in the electron superconducting main linac, containing the chicane system for the ~200 m superconducting undulator system for producing high-energy photons; the photon collimator and titanium-alloy target system; flux concentrator and the conventional RF capture section; the 5 GeV superconducting injector linac; spin rotators and large aperture transport lines, up to connection to the positron damping ring. Responsibilities include all associated accelerator beamline components (magnets, vacuum, instrumentation), but not the superconducting injector linac, with the exception of specifying its general parameters and CFS requirements.

Critical R&D for the ED phase includes:

- Design and prototyping of the superconducting undulator
- High-velocity rotating titanium target, specifically survivability and eddy current studies
- Design of a feasible optical matching device to maximise the yield, this could be a high-field pulsed flux concentrator or a lithium lens system

In addition to the fundamental engineering goals, key deliverables are

- Full prototype section and evaluation of the superconducting helical undulator (2009)
- Feasibility studies and design of a high-field flux concentrator (2009)
- Feasibility study and design of a lithium lens (2010)
- Engineering design of rotating target system with appropriate lifetime (2010)

Table B.9: Positron Source Work Packages

ID	title	description
3.2.1	Undulator System	Design of the undulator section, including photon collimators, quads, correctors, etc. Construction and evaluation of a full scale undulator prototype. Electron beam dynamics and lattice integration.
3.2.2	Target System	Design and specification of rotating target, vacuum vessel, cooling system, and other associated instrumentation. Construction and evaluation of prototype titanium wheel target. Comprehensive stress analysis of the target. Analysis of use of cooled / non-cooled beam windows.
3.2.3	Capture Magnet	Specification, design and evaluation for options for the high-field pulsed capture magnet system. Integration of device with rotation target.
3.2.4	RF Capture System	Specification, design and performance evaluation of the normal conductive RF capture section (structure, HLRF requirements and layout), including prototyping of the capture structure.
3.2.5	Dumps and Collimators	Feasibility study and design of high-powered photon collimator. Specification and design of other photon and electron beam collimators and dumps.
3.2.6	Polarisation Issues	Requirements for polarimetry; spin-transport performance; expected degree of spin polarisation etc. Spin-flipping solution.

3.2.7	Auxiliary Positron Source	Integrated design and specifications for the auxiliary positron source. Evaluation of requirements, specifically as a 'keep alive' source.
3.2.8	Remote Handling / Target Hall	Develop a cost-effective remote handing solution for the photon target and capture section. Develop maintenance models in support of design.
3.2.9	System Integration	Overall management and coordination of work packages. Integration of sub-components and sub-systems. Overall performance evaluation. Primary interface for CFS/Global and SRF Tech. requirements and criteria
3.2.10	Lattice Design	Optics lattice design work for both the high-energy electron insert and the positron capture, transport and DR injection systems.
3.2.11	Alternative Compton Source	Continued design of an independent positron source based on laser Compton scattering. This work package covers all aspects of the complete source system, which is primarily an R&D activity.
3.2.12	Magnets	Conceptual/engineering design of conventional magnets and supports.
3.2.13	Power supplies	Specifications, layout and cable layout of magnet power supplies
3.2.14	Beamline Vacuum	Specification and design of the vacuum system (not including SRF cold vacuum section).
3.2.15	Beam Instrumentation	Specification, design and eventual prototyping of required beam instrumentation, including timing requirements and controls interface specifications.

TA-3.3 Damping Rings

Responsibilities include the complete integrated design of the electron and positron ~6.7 km circumference damping rings, including conventional magnets, vacuum system, superconducting damping wiggler magnets, 650 MHz superconducting RF system, injection and extraction systems.

Overall Objectives and Deliverables

The principle objectives for the Damping Rings R&D during the ILC Technical Design Phase are:

1. To consolidate the design described in the Reference Design Report, and develop a better understanding of the cost drivers and technical limitations
2. To identify and explore opportunities for reduction of cost and technical risk, and implement design changes to take advantage of such opportunities where possible
3. To demonstrate key technical performance goals (including electron cloud mitigation; ultra-low emittance operation; and performance of fast injection/extraction kickers) at the test facilities

The principle deliverables will be:

1. A report describing an updated design, together with a more detailed and reliable cost estimate
2. A set of reports describing studies validating the design in terms of beam dynamics effects and describing individual components (magnets, rf cavities, vacuum components etc.) in appropriate detail
3. Results from the test facilities demonstrating key technical performance goals

Organisational Structure: Work Packages

Damping Rings R&D activities in the Technical Design Phase will be coordinated within a structure of five Work Packages (WP1-5):

WP 3.3.1: CesrTA

WP 3.3.2: Damping Ring Studies at KEK-ATF

WP 3.3.3: Damping Ring Studies at DANE and Other Facilities

WP 3.3.4: Lattice Design and Beam Dynamics

WP 3.3.5: Technical Subsystems and Components

The first three Work Packages emphasise the importance of the test facilities. The objectives are described more completely below, but key objectives for Work Packages 3.3.1-3 include:

- Validation of electron cloud models and suppression techniques
- Demonstration of reliable operation at ultra-low vertical emittance
- Demonstration of fast kickers meeting the specifications for the ILC damping ring injection/extraction kickers

Work Package 3.3.4 includes all beam dynamics issues, including: lattice design and optimisation for the damping rings and injection and extraction lines; development and modelling of low-emittance tuning techniques; modelling of collective effects, including electron cloud, ion instabilities, intra-beam scattering, impedance-driven instabilities.

Work Package 3.3.5 includes technical design studies and cost optimisation for components and subsystems, including: vacuum system; magnets; RF system; instrumentation and diagnostics etc.

There are clearly (and deliberately) many areas of overlap between the Work Packages. Ensuring effective communication and exchange of information between the Work Packages will be a key responsibility of the Damping Rings Area System Manager and the individual Work Package Managers. The Area System Manager will also have responsibility for communication with other Area Systems (e.g. Sources, RTML etc.)

Table B.10: Damping Ring Work Packages

ID	Title	description

3.3.1	CesrTA	Validation of electron cloud modelling tools (including build-up and instability simulations) in a parameter regime relevant for the ILC damping rings. 2. Demonstration of techniques for mitigation of electron cloud effects, which will allow operation of the ILC damping rings meeting specifications for beam quality and stability. 3. Demonstration of tuning techniques to achieve vertical emittance below 10 pm. 4. Development of x-ray beam-size monitor to characterise ultra-low emittance beams.
3.3.2	KEK-ATF Studies	1. Demonstration of (low current) operation at 2 pm vertical emittance. 2. Characterisation of selected collective effects (including ions and intra-beam scattering) in the ultra-low vertical emittance regime. 3. Demonstration of fast kickers meeting the specifications for the ILC damping rings.
3.3.3	DAΦNE and other Test Facilities	1. Collection of data on electron cloud effects, and tests of mitigation techniques. 2. Tests of fast kickers meeting the specifications for the ILC damping rings.
3.3.4	Lattice Design and Beam Dynamics	1. Optimisation of baseline lattice design, including the damping rings and injection/extraction lines, identifying and implementing opportunities for reduction of costs and technical risks. 2. Characterisation of injection efficiency, taking into account magnet field and alignment errors and injected beam distribution and jitter. 3. Specification of electron-cloud mitigation techniques, based on results of studies from the test facilities (WP1 and WP3), and characterisation of safety margins using benchmarked simulation codes. 4. Development of an impedance model based on scaling from existing machines and technical design of vacuum and rf components (from WP5) as these become available. Characterisation of impedance-driven single-bunch and multi-bunch instabilities, and specification of feedback system requirements. 5. Characterisation of ion effects using simulation codes benchmarked against data from the test facilities (WP2). 6. Characterisation of other beam dynamics effects, as resources permit.
3.3.5	Technical Subsystems and Components	1. Development of technical designs and reliable cost estimates for subsystems and components, including: 1.1. vacuum system; 1.2. magnets (dipoles, quadrupole, sextupoles, orbit and skew quadrupole correctors); 1.3. damping wiggler; 1.4. magnet power system; 1.5. magnet supports and alignment systems; 1.6. injection and extraction systems; 1.7. RF system; 1.8. instrumentation and diagnostics; 1.9. control system. 2. Identification of cost drivers and implementation of cost reductions where possible. 3. Provision of information for design and costing of conventional

		facilities and consideration of site-dependent issues.

TA-3.4 Ring to Main Linac (RTML)

The RTML sections connect the Damping Rings (5 GeV beam energy) to the beginning of the 1.3 GHz superconducting Main Linacs (15 GeV beam energy). They include: the long transport lines (including collimation and diagnostics sections) form the centrally located DR to geometrical ends of the collider complex; the 180 degree turn-around beamlines, spin rotator sections, two-stage bunch compressor section. Responsibilities include all associated accelerator beamline components (magnets, vacuum, instrumentation), but not the superconducting linacs used in the two bunch compressors, with the exception of specifying their general parameters, layout and CFS requirements.

Critical R&D for the ED phase includes:

- Critical phase tolerance required for the bunch-compressor RF

In addition to the fundamental engineering, key deliverables are

- Experimental demonstration of the bunch compressor RF phase stability, and beam loading compensation
- Results of beam dynamics simulation, demonstrating the required emittance tuning techniques

Table B.11: Ring to Main Linac Work Packages

ID	Title	description
3.4.1	Engineering Lattice Design	Optics lattice design, including incorporating all major sub-systems of the RTML. Specification of all Accelerator components.
3.4.2	Specification Development	Consolidate and document specification for all components of the RTML, specs for the technical systems, tolerances, alignment.
3.4.3	Accelerator Physics	Simulate performances of the RTML system and define the major specifications for components, (alignment, stability).
3.4.4	Bunch Compressor Phase Stability	Develop the necessary LLRF and timing systems to achieve the required phase and amplitude stability for the bunch compressors. Experimentally verify performance.
3.4.5	Alternative short bunch compressor	Continue design effort and performance evaluation of the alternative short bunch compressor system.
3.4.6	Magnets and Power Supplies	Conceptual/engineering design of conventional and superconducting magnets and supports. Specifications, layout and cable layout of magnet power supplies.
3.4.7	Halo Collimation System	Optics design of the post damping ring halo collimation system, including performance evaluation (simulation), of both collimation

		efficiency and wakefield effects.
3.4.8	Beam Dump Systems	Optics design of beam extraction line(s). Radiation/activation calculations of dump environment (shielding requirements). Technical specifications of dumps and beamline components.
3.4.9	Beamline Vacuum	Specification and design of complete vacuum system. Specification of sub-components. Estimation of impedance issues.
3.2.10	Beamline Instrumentation	Specification, design and eventual prototyping of required beam instrumentation, including timing requirements and controls interface specifications. Design/specification of feedback/feedforward systems.
3.2.11	CFS Specifications	Responsible for collecting and consolidating the critical key CFS requirements (space, water cooling, power etc.). This work package acts as the primary contact to the CFS Technical Areas.

TA-3.5 Beam Delivery System (BDS)

The Beam Delivery Systems transport the high-energy beams from the exit of the 1.3 GHz superconducting Main Linacs, to the Interaction Region (IR), where they are focused and brought into collision. The beams are then cleanly extracted from the IR to high-powered beam dumps. The BDS includes post-linac halo collimation system, diagnostics and tuning sections; emergency machine-protection fast beam extraction (beam abort) system; final focus section. Responsibilities include all associated accelerator beamline components (magnets, vacuum, and instrumentation), detector background suppression systems (e.g. muon toroid systems), interfaces to detector and HEP-related beam instrumentation (precision energy spectrometers, polarimeters etc.).

Critical R&D for the ED phase includes:

- Compact superconducting final-doublet, together with its integration into the machine-detector interface.
- 3.9 GHz superconducting crab-cavity technology

In addition to the fundamental engineering key deliverables are

- Prototype and performance evaluation of compact superconducting final-doublet quadrupole
- Prototype and performance evaluation of the 3.9 GHz superconducting crab-cavity system, including demonstration of the required phase stability and alignment
- Cost-optimised engineering design of machine detector interface area and experimental hall

Table B.12: Beam Delivery System Work Packages

ID	title	description
3.5.1	Management and Integration	Overall management and coordination of work packages. Integration of sub-components and sub-systems. Overall performance evaluation. Primary interface for CFS/Global requirements and criteria (including MDI).
3.5.2	ATF2 Test Facility	All work and programmes at ATF and ATF2 related to the ILC BDS. Specification, definition and implementation of experiments, within the context of the ATF2 International Collaboration.
3.5.3	Accelerator Physics	Design and development of the engineering lattice. System-wide integration and parameters. Performance evaluation studies; accelerator component specifications; alignment and stability requirements; beam tuning requirements. Analysis of alternative design
3.5.4	IR and IR Integration	Engineering design of detector / accelerator interface (Interaction Region). Design and prototyping of final doublets. Definition of interface boundaries and constraints between machine components and detectors.
3.5.5	Crab Cavity	Development of the superconducting RF crab system (cavity design, coupler, HOM etc.) Demonstration of performance (prototype). Design of complete system, including HLRF and LLRF requirements. Evaluation of wakefield and alignment tolerances.
3.5.6	Beam Dump Systems	Design and specification of the high-powered 17MW beam dumps and their associated systems.
3.5.7	Collimation Systems	Mechanical design of spoilers for primary halo collimation system, protection collimators and IR masks. Analysis of beam damage and wakefield performance, including beam tests. Optimisation of lattice location and optics. Evaluation of halo collimation performance.
3.5.8	Magnets and Power Supplies	Conceptual/engineering design of conventional and superconducting magnets (not the final doublet) and supports. Specifications, layout and cable layout of magnet power supplies. Includes pulsed magnet systems.
3.5.9	Beamline instrumentation	Specification, design and eventual prototyping of required beam instrumentation, including timing requirements and controls interface specifications. Design/specification of feedback/feedforward systems.
3.5.10	Beamline Vacuum	Specification and design of complete vacuum system. Specification of sub-components. Performance estimation (simulation), including impact on detector background. Impedance issues.

TA-3.6 Simulation

The Simulation Group provides a centralised group for beam dynamics simulations, with a particular focus RTML, Main Linacs and BDS systems. While each of the Technical Area Groups 3.1-5 contain work packages for beam dynamics and accelerator physics activities related to that specific section of the ILC, the simulations groups provides an overall collaboration environment, and facilitates both cross-checking and benchmarking of simulations, development of simulation tools (codes), as well as being primarily responsible for developing start-to-end simulations of the entire accelerator systems.

Critical R&D for the ED phase includes:

- Start-to-end models of accelerator, including static tuning and simulation of time-dependent stability (beam-based feedback systems), leading to a realistic estimate of the luminosity performance of the machine.

Key deliverables are

- Answers to critical beam-dynamics questions arising during the TD Phase (engineering driven)
- Overall (simulated) demonstration of emittance preservation from the Damping Rings to the interaction point
- Modelling of halo generation, transport and collimation
- Software tools (simulation codes)

Table B.13: Simulations Work Packages. Note that these packages have strong connection to accelerator physics packages in TA Groups 3.1-4 and 1.5.

ID	Title	description
3.6.1	RTML Beam Dynamics	Demonstration of the emittance preservation in the RTML, leading to the specification of the emittance tuning requirements (tuning magnets, instrumentation, installation alignment tolerances etc.)
3.6.2	Main Linac Static Tuning	Continued development of complex models to evaluate the performance of beam-based alignment and emittance tuning techniques in the Main Linacs.
3.6.3	Main Linac Dynamic Tuning	Continued development of complex models to evaluate the time-dependent behaviour of the Main Linac emittance, including environmental effects such as vibration and slow component drift. Evaluation/specification of beam-based feedback systems.
3.6.4	BDS Beam Dynamics	Simulations of luminosity tuning requirements; demonstration that the design luminosity can be achieved with 90% confidence, using standard assumptions about the initial alignment of components and field quality.

3.6.5	ATF2 beam dynamics simulations	Beam dynamics simulations relevant to the design and operation of ATF-2 test facility.
3.6.6	Feedback and Feedforward	Develop a model of the beam-based trajectory feedback and feedforward system; simulate performance.
3.6.7	Control of longitudinal phase space.	Develop a model of the control system in the longitudinal phase space of the beam; simulate performance.
3.6.8	Start-to-End Model	Integrated model of the RTML, Main Linac, and BDS, providing a common simulation framework to produce estimates of the ILC luminosity, incorporating static tuning algorithms, dynamic effects and feedback/feedforward systems, and the beam-beam interaction
3.6.9	Accelerator-Related Detector Background	Produce models for accelerator-related background sources for the physics detector; simulation of halo collimation system(s); estimation of impact on physics detector. Sources of accelerator-related background included are: beam halo; synchrotron radiation
3.6.10	Machine Protection Models	Modelling of possible failure modes and estimation of their damage potential.
3.6.11	Particle Spin Dynamics	Modelling and simulation of the electron and positron spin transport; estimation of spin preservation from the source to the interaction point; simulations of spin tuning algorithms.

Appendix C: Summaries of Activities useful for ILC TD Phase R & D

C.1: Introduction

The GDE Technical Design Phase will make extensive use of synergy with existing or planned projects and infrastructures which are not directly related to ILC, and which have separate lines of (project) funding.

The following SCRF projects and infrastructures are of significant benefit to ILC R & D:

- At DESY, Germany, the TESLA Test Facility linac is now used to drive the VUV-FEL “FLASH” user facility. The linac itself and the related infrastructure (in operation since 1995) are the basis for the SCRF linac technology.
- The European XFEL, due to start construction in 2008 at DESY, will use a 17.5 GeV SCRF linac to provide X-Ray light to photon users starting in 2013.
- The Fermilab test facility ‘NML’, currently under construction, will complement the SCRF infrastructure at DESY, providing a multi-purpose SCRF development facility including a test linac.

As a secondary role, these facilities provide a test bed for regionally produced linac technical components. For each case, many of the planned activities are either directly applicable to the ILC, or have a peripheral connection to it. Support for construction, development and operation of these facilities is not directly associated with the ILC TD Phase Plan.

The Compact Linear Collider (CLIC) R&D programme based at CERN also has a large overlap with the ILC programme, specifically for common technical areas such as CFS and the conventional (i.e. non-SCRF) accelerator systems, where many of the challenges are similar.

These efforts are listed here for completeness and because they are of vital importance to the ILC TD Phase.

C.2: XFEL Project

The European XFEL is primarily a European international project centred at DESY, Germany. The project was formally approved in June 2007. The XFEL’s 17.5 GeV superconducting linac will be constructed from a technology essentially the same as that foreseen for the ILC (with the notable exception of the accelerating gradient). Between now and 2012, the European XFEL collaboration will construct a total of 101 cryomodules, requiring 808 superconducting 1.3 GHz TESLA nine-cell cavities (including high-power couplers, tuners, HOM pick-ups). The total construction cost of the project is estimated at 850 M€, of which the superconducting linac is approximately 181 M€. The linac will be constructed by a collaboration of institutes from Italy, France, Germany, Poland, Russia, and Spain.

By publication of the ILC TD Phase in mid-2010, approximately 60% of the linac total cost is currently planned, during which time the industrialised production rate will be ramped up to a peak of approximately one cryomodule per week. By the end of CY 2010, it is expected to have tested the first (~5) production XFEL cryomodules.

The ILC TD Phase runs essentially in parallel with the XFEL R&D and industrialisation phase. Table C.1 lists several of the key ILC-relevant XFEL milestones up to 2010.

Table C.1: Examples of TD Phase relevant XFEL milestones

2008	30 high-gradient cavities with initial (bulk) electro-polishing by industry (final polishing at DESY)	Input into ILC S0 programme
	Construction and testing (on DESY test stand) of new high-gradient cryomodule (Module 8)	Input for ILC S1 programme
2009	Additional 2 (possibly 3) cryomodules (Modules 9, 10 and 11).	Input for ILC S1 programme. Design for transport.
	30 industry produced EP's cavities (pre-mass production series)	Input into S0 programme*
	Construction of Accelerator Module Test facility (AMTF) at DESY.	New test facility for XFEL mass-production testing.
	Module 8 installed in TTF (FLASH) linac	Beam tests, input to ILC S2 programme.
2010	XFEL pre-production series (3 modules), used also to commission AMTF.	Feedback from industrialisation*.
	Continued ramp-up of cavity production.	Further (mass production) statistics. (Note all cavities will be vertically tested to maximum achievable gradient.)

*) Degree of ILC benefit depends on final choice of surface preparation process for XFEL mass-production.

During the period 2008-2010, the XFEL project will gradually transition from R&D (including industrialisation) to production. Table C.2 shows the total expected (planned) resources for the XFEL linac from 2007-2010, and those remaining resources considered specifically R&D (preparatory phase) for DESY.

Table C.2: Expected total XFEL linac resources and remaining (DESY-specific) linac R&D for the ILC ED phase period.

		Total FTE	Total M&S	
DESY XFEL linac R&D	2007-2009	155	10 M€	Remaining preparatory phase funding, which ends in 2009.
Total XFEL linac	2007-2010	485	109 M€	~60% of total cost of XFEL linac.

C.3: Fermilab SCRF Infrastructure (NML)

During the period 2008-2010, development of infrastructure for the Fermilab-based test facility project is planned. Table C.3 shows the total expected (planned) resources for this activity.

Table C.3: Resources anticipated for the development of the Fermilab-based test facility related infrastructure for the US fiscal years 2008 through 2010.

Total FTEs (2008-2010)	85	FTE
Total M&S (2008-2010)	9200	$k

C.4: CLIC

The Compact Linear Collider Collaboration, centred at CERN, will develop the two-beam accelerator technology and related linac design concepts during the coming years. Much of the work on global systems, especially that work devoted to conventional facilities, will have substantial overlap with the corresponding work for the ILC Main Linac. The TD Phase R & D Plan includes the development of work packages that have a strong overlap between CLIC and ILC efforts.

Appendix D: Participating Institutes.

Abertay University, UK
Argonne National Laboratory, USA - ANL
Bhabha Atomic Research Center, India - BARC
Birmingham University, UK
Budker Institute of Nuclear Physics, Russia - BINP
Brookhaven National Laboratory, USA - BNL
Cambridge University
CEA, Centre de Saclay, France
Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas, Spain - CIEMAT
Cockroft Institute, UK
Colorado University, USA
Cornell University, USA
Daresbury Laboratory, UK
Deutsches Elektronen-Synchrotron, Germany – DESY
Dundee University, UK
Durham University, UK
European Organization for Nuclear Research, EU - CERN
Efremov Scientific Research Institute, Russia
Fermi National Accelerator Laboratory, USA – FNAL
Florida State University, USA – FSU
Hiroshima University, Japan
Instituto de Fisica Corpuscular, Spain - IFIC
Institute of High Energy Physics, China - IHEP
Institute for Particle Physics Phenomenology, UK – IPPP
Inter University Accelerator Centre, India - IUAC
Istituto Nazionale di Fisica Nucleare - INFN
Joint Institute for Nuclear Research, Russia - JINR
KEK - High Energy Accelerator Research Organization, Japan
Kharkov Institute of Physics and Technology, Ukraine - KIPT
Kyoto University, Japan
Kyungpook National University, Korea - KNU
Laboratoire de l’accelérateur linéaire Orsay, France – LAL Orsay
Laboratoire d'Annecy-le-Vieux de Physique des Particules, France - LAPP
Laboratori Nazionale di Frascati, Italy – INFN-LNF
Lancaster University, UK
Lawrence Berkeley National Laboratory, USA - LBNL
Lawrence Livermore National Laboratory, USA – LLNL
Liverpool University, UK
Los Alamos National Laboratory, USA - LANL
Manchester University, UK
Moscow University, Russia

Michigan State University, USA – MSU
Nagoya University, Japan
Oxford University, UK
Pohang Accelerator Laboratory, Korea - PAL
Royal Holloway, University of London, UK - RHUL
Raja Ramanna Centre for Advanced Technology, India - RRCAT
Stanford Linear Accelerator Laboratory, USA - SLAC
Tata Institute of Fundamental Research – TIFR
Thomas Jefferson National Accelerator Facility, USA - JLab
Tohoku University, Japan
University of Tokyo, Japan
Tri-University Meson Facility, Canada - Triumf
University of British Columbia, Canada - UBC
University College London, UK – UCL
University of Illinois at Urbana Champaign, USA - UIUC
University of Iowa, USA
University of Michigan, USA - UM
University of Notre Dame, USA
University of Oregon, USA
University of Pennsylvania, USA – UPEN
University of Wisconsin, USA
Variable Energy Cyclotron Centre, India - VECC
Yale University, USA